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SUPPLEMENTAL DECLARATION FOR REISSUE PATENT APPLICATION TO CORRECT "ERRORS" STATEMENT (37 CFR 1.175)

Attorney Docket Number	2115D-000939/DVC
First Named Inventor	Gerald A. Mourou
COMPLETE	
Reissue Application No.	09/775,106
Filing Date	February 1, 2001
Art Unit	1725
Examiner Name	Geoffrey S. Evans

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Name of Sole or First Inventor:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle [if any])	Family Name or Surname		
Gerard A	**Mourou**		
Inventor's Signature		Date	
Name of Second Inventor:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle [if any])	Family Name or Surname		
Detao	**Du**		
Inventor's Signature		Date	
Name of Third Inventor:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle [if any])	Family Name or Surname		
Subrata K.	**Dutta**		
Inventor's Signature		Date	
Name of Fourth Inventor:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle [if any])	Family Name or Surname		
Victor	**Elner**		
Inventor's Signature		Date	

√ Additional inventors or legal representatives(s) are being named on the __1__ supplemental sheets PTO/SB/02A or 02LR attached hereto.

PTO/SB/51S (05-03)

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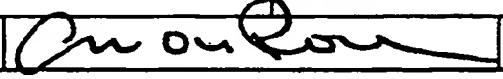
Given Name (first and middle [if any])	Family Name or Surname		
Gerard A	Mourou		
Inventor's Signature		Date	8/11/04
Name of Second Inventor: ☐ A petition has been filed for this unsigned inventor			
Given Name (first and middle [if any])	Family Name or Surname		
Detao	Du		
Inventor's Signature		Date	
Name of Third Inventor: ☐ A petition has been filed for this unsigned inventor			
Given Name (first and middle [if any])	Family Name or Surname		
Subrata K.	Dutta		
Inventor's Signature		Date	
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Victor	Elner		
Inventor's Signature		Date	

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Inventor's Signature		Date	
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Subrata K.	Dutta		
Inventor's Signature		Date	
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Detao	**Du**		
Inventor's Signature		Date	8/3/04
Name of Third Inventor:	☐ A petition has been filed for this unsigned inventor		
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Inventor's Signature		Date	
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	First Named Inventor	Gerald A. Mourou,
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Given Name (first and middle [if any])	Family Name or Surname		
Subrata K.	Dutta		
Inventor's Signature	Subrata Dutta	Date	8/5/04
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Inventor's Signature		Date	

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Inventor's Signature		Date	9/4/04

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DECLARATION	ADDITIONAL INVENTOR(S) Supplemental Sheet Page 2 of 2

Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle if any)		Family Name or Surname	
Ron		Kurtz	
Inventor's Signature		Date	
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Paul R.		Lichter	
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Xinbing		Liu	
Inventor's Signature		Date	
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Peter P.		Pronko	
Inventor's Signature		Date	
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Given Name (first and middle if any)		Family Name or Surname	
Jeffrey A.		Squier	
Inventor's Signature		Date	

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Ron		Kurtz	
Inventor's Signature	Ron Kurtz	Date	8-6-04
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Inventor's Signature		Date	
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Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor		
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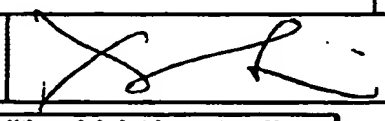
Inventor's Signature		Date	Aug. 3, 2004
Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor		
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Jeffrey A.		Squier	
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SUPPLEMENTAL DECLARATION FOR REISSUE PATENT APPLICATION TO CORRECT "ERRORS" STATEMENT (37 CFR 1.175)

Attorney Docket Number	2115D-000939/DVC
First Named Inventor	Gerald A. Mourou
COMPLETE	
Reissue Application No.	09/775,106
Filing Date	February 1, 2001
Art Unit	1725
Examiner Name	Geoffrey S. Evans

I/We hereby declare that:

Every error in the patent which was corrected in the present reissue application, and which is not covered by the prior oath(s) and/or declaration(s) submitted in this application, arose without any deceptive intention on the part of the applicant.

I/We hereby declare that all statements made herein of my/our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Name of Third Inventor: ☐ A petition has been filed for this unsigned inventor			
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Subrata K.	Dutta		
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Feature Article: solid state

The dawn of organic electronics

Organic semiconductors are strong candidates for creating flexibl color displays and circuits on plastic

By Stephen Forrest, Princeton University, Paul Burrows, Pacific Northwest Natic Laboratories & Mark Thompson,University of Southern California

ORGANIC MATERIALS ARE POISED AS NEVER BEFORE TO TRANSFORM the wc circuit and display technology. Major electronics firms such as Philips and Pioneer, an companies such as Cambridge Display Technology, Universal Display, and Uniax, are that the future holds tremendous opportunity for the low cost and sometimes surprisin performance offered by organic electronic and optoelectronic devices. Using organic li emitting devices (OLEDs), organic full-color displays may eventually replace liquid-cry displays (LCDs) for use with laptop and even desktop computers. Such displays can b deposited on flexible plastic foils [Fig. 1], eliminating the fragile and heavy glass substi in LCDs, and can emit bright light without the pronounced directionality inherent in LCI all with efficiencies higher than can be obtained with incandescent light bulbs.

Organic electronics are already entering the commercial world. Multicolor automobile s displays are now available from Pioneer Corp., of Tokyo, and Royal Philips Electronics Amsterdam, is gearing up to produce both OLED backlights to be used in LCDs and o integrated circuits. It is possible that soon, portable and lightweight roll-up OLED displ cover our walls, replacing the bulky and power-hungry cathode ray tube that has been television standard for 50 years.

Given the need for very low-cost (but not always high-performance) circuits for everyth smart cards carrying personal information, to building entry cards, to inventory control, reasonable to assume that within 10 years, the square footage of organic circuitry mig that of silicon electronics (though one expects that silicon transistors would still vastly and outperform those fabricated from organic materials.)

Organic semiconductors have been the subjects of intense scientific investigation for t years. During most of that time, these materials, primarily consisting of carbon, hydrog oxygen, were considered to be merely a scientific curiosity. Organic materials' weak intermolecular bonds in the solid state give them properties of both semiconductors ar insulators; so their study has deepened our fundamental understanding of the electror optical properties of solids. But, organic semiconductors attracted industrial interest wl recognized that many of them are photoconductive under visible light. This discovery l use in electrophotography (or xerography) and as light valves in LCDs. There were ev that very low-cost thin-film solar cells and superconductors could be made using such

substances.

Unfortunately, the potential of active electronic devices such as solar cells, light emitte thin-film transistors remained unfulfilled for decades because organic materials have c proved to be unstable. Further, making reliable electrical contacts to organic thin films and when exposed to air, water, or ultraviolet light, their electronic properties can degr rapidly. Finally, the low carrier mobilities characteristic of organic materials obviates th high-frequency (greater than 10 MHz) applications. These shortcomings are compoun difficulty of both purifying and doping the materials.

But in 1987 Ching Tang and Steven Van Slyke of Eastman Kodak Co., Rochester, N.Y successfully addressed many of these problems when they produced the first efficient emission from a two-layer organic structure resembling a pn junction. The Kodak grou class of synthetic dyes that is closely related to well-understood xerographic materials a device called a small-molecule OLED that produced light with about 1 percent efficie materials used consist of often no more than 30 or 40 atoms covalently bonded into st individual molecular units, called monomers.

While this first demonstration of reasonably efficient light emission at low voltage attra interest from potential display manufacturers, particularly in Japan, the technology attr public attention when, in 1990, researchers at Cambridge University in England under direction of Richard Friend reported a similar effect in a semiconducting organic polym consisting of poly para-(phenylene vinylene), or PPV. Unlike small molecule compoun polymers are long chain molecules whose monomer segments are attached in a conti covalently bonded, high-molecular- weight chain. Polymers tend to be environmentally and flexible although, like small molecules, their electronic properties can rapidly degr exposed to oxygen or water.

Let There Be Light

Both polymeric and small molecule OLEDs [Fig. 2] operate by accepting charge carrie opposite polarities, electrons and holes, from the cathode and anode contacts, respec externally applied voltage drives these carriers into the recombination region where th neutral bound state, or exciton. There are two types of excitons formed, called singlets triplets. On average one singlet and three triplets are formed for each four electron-hol injected into the exciton formation region of the OLED.

Quantum mechanics allows de-excitation (or recombination) of the singlet within a few nanoseconds of formation. This leads to a photon emission and is called fluorescence Recombination of the triplet exciton is slow (taking about 1 ms to 1 second) and when occur, usually results in heat rather than light. But if a heavy- metal atom such as iridi platinum is placed in an otherwise organic molecule, the characteristics of singlet and excitons mix, speeding the emission of light to within 100 ns-100 μs. This kind of emis called phosphorescence.

Recent advances in boosting the efficiency of OLED light emission have led to the pos OLEDs will find early uses in many battery-powered electronic appliances such as cell gameboys, and personal digital assistants. Typical external quantum efficiencies of OL (defined as the ratio of the number of emitted photons to the number of injected electr using a single fluorescent material that both conducts electrons and radiates photons than 1 percent.

But by using guest-host organic materials systems where the radiative guest fluoresce phosphorescent dye molecule is doped at low concentration (typically between 0.5 an percent) into a conducting molecular host thin film, the efficiency can be substantially i to 10 percent or higher for phosphorescence or up to approximately 3 percent for fluor

Currently, efficiencies of the best doped polymer and molecular OLEDs exceed that of

incandescent light bulbs. Efficiencies of 20 lumens per watt have been reported for yel emitting polymer devices, and
40 lm/W attained for phosphorescent molecular OLEDs, compared to less than 20 lm/ typical incandescent light bulb. It is reasonable to predict that soon, efficiencies of 80 l value comparable to that of fluorescent room lighting--will be achieved using phospho OLEDs.

A fundamental difference between small -molecule and polymeric devices is the mann they are constructed. Small molecules are deposited in thin layers around 5-100 nm b vacuum thermal sublimation. That technique heats powder sources of the molecules i to a temperature high enough to evaporate, but low enough to avoid their decompositi 250 ° to 450 ° C). The evaporated molecules then collect on a cool substrate to form a thickness can be precisely controlled to near monolayer accuracy.

Small-molecule OLEDs are grown on a glass or plastic substrate to form a multi-layer about 100 nm thick [Fig. 2]. The substrate is first coated with a conducting transparent such as indium tin oxide (ITO) or polyaniline, which serves as the anode. This is follow thin, hole-transporting organic layer (HTL) typically made from chemicals called diamir organic light-emitting layer of comparable thickness is then deposited onto the HTL su latter stratum often doubles as the electron-transporting layer (ETL). Finally, the devic completed by depositing a cathode consisting of a metal with a low work function such calcium or an alloy such as magnesium-silver onto the ETL surface. A low work functi necessary to ensure efficient, low-resistance injection of electrons from the cathode in

Changing the composition of the layers tunes the OLED emission colors across the vi spectrum. Green emission can be achieved by doping an electron-conducting organic called Alq_3 with either a small amount of an iridium phosphor or fluorescent dyes. The perylene when doped into an ETL known as CBP emits blue light. Lanthanide comple porphyrin pigments have been used to efficiently emit red light when doped into Alq_3 o

Researchers have encountered many difficulties in manufacturing devices with the thi needed to achieve operating voltages between 5 V and 10 V. OLEDs are vulnerable t caused by pinhole defects in the film or contamination of the substrate surface by dust Furthermore, the materials tend to be mechanically fragile and are easily attacked by used in photolithographic patterning. Therefore, patterning often requires low-resolutio such as defining the device contact by metal deposition through a shadow mask, ofter combination with costly dry- processing techniques. In the future, however, many new nanolithographic patterning techniques will appear and even techniques borrowed fror industries such as injection molding, direct imprinting using stamping, and ink jet printi

The most efficient polymer-based devices use bilayer structures similar to molecular o devices or blends of electron- and hole-transporting materials. In contrast to vacuum-s small-molecule OLEDs, polymers, or their precursors are typically cast as a liquid ontc tin-oxide-coated substrates. Then, once the film has been thinned by spinning the sub other methods, it is solidified by heating. While the application of the organic layers oc such potentially low-cost wet-chemistry processes, a low-work-function metal cathode be vacuum deposited.

Polymer OLED structures can be simpler than small-molecule structures. The first poly (in contact with ITO) can serve solely as a hole-injecting/conducting layer; in some cas layer is used for electron and hole injection, conduction, and light emission. Polymer C often operate at lower power than small-molecule devices. Due to their high conductiv polymer-based devices have operating voltages in the 2-5-V range, which is 1-2 V low small-molecule OLEDs.

Control of film composition and thickness uniformity to dimensions required in single- a layer OLEDs is straightforward by vapor deposition but problematic by spin-on techniq

polymers are cast from solution, care must be taken in multilayer structures to ensure solvent used for the second layer does not dissolve the first. Hence, chemical compati between successively applied polymers ultimately limits the complexity of the device s fabricated using these materials.

As in small-molecule devices, changing the chemistry of the polymer can tune the colc OLED. For example, adding electron-donating groups to the PPV chain red-shifts its li emission to orange. Conversely, adding electron-acceptor groups gives a blue shift. Si are obtained in the Alq_3 system by adding methyl groups to a particular chemical struc However, even such simple chemical substitutions can change the device efficiency ai reliability in an unpredictable manner.

And Full-Color Displays

One of the principal reasons that OLED technology has attracted such intense interest potential for use in full-color displays that might eventually replace active- matrix LCDs consists of a matrix of contacts made to the bottom and top surfaces of each organic li emitting element, or pixel [see "Organic displays"]. To generate a full-color image, it is to vary the relative intensities of three closely spaced, independently addressed pixels emitting one of the three primary colors of red, green, or blue.

Several different techniques have been proposed for producing the three colors neede pixel [Fig. 3]. One method involves photolithographic patterning of the transparent indi oxide anode column electrodes on the substrate combined with deposition of metal thr mask to form the cathode row electrodes of the side-by-side-positioned red, green, an G, B) subpixels, as shown at the top left of the figure. This approach, while architectur obvious, requires a costly process where each of the three closely spaced color segm be sequentially grown and patterned. In spite of this difficulty, Sanyo Electric Co. of Os Japan, and Kodak recently demonstrated a prototype side-by-side molecular OLED fla [Fig. 4].

Alternatively, optical filtering of white OLEDs can produce acceptable red, green, and l emission, as seen in the next diagram down in Fig 3. But this method sacrifices efficie the large amount of light absorbed in the filters. Less efficiency is lost by using a single ultraviolet OLED to pump organic fluorescent wavelength down-converters, also know changing media (CCM), as illustrated in the third diagram on the left of Fig 3. Each CC consists of a material that efficiently absorbs the blue light and re-emits the energy as green or red light, depending on the compound used.

Organic thin films allow for the realization of completely new display architectures, whi other advantages, may lead to the practical realization of low-cost, very high-resolutior displays. For example, Vladimir Bulovic and co-workers at Princeton University in New demonstrated transparent OLEDs (or TOLEDs), that could be used in either transpare or high-contrast displays.

In addition to being a transparent light emitter, the top indium-tin-oxide surface of the T serve as the hole- injecting electrode for a second TOLED built on top of the first devic shown in the bottom left diagram of Fig. 3. Each device in the stack is then independer addressable and can be tailored to emit its own color through the adjacent transparent layers, the transparent contacts, and the glass substrate. This allows the entire area o vertically stacked pixel to emit any mixture of the three primary colors.

Recently the authors' laboratory constructed a full-color, transparent stacked OLED (S the configuration shown in the bottom left diagram of Fig. 3]. Because each color elem stack is independently addressable, a SOLED display can be built with independent c brightness, color, and gray scale. Although somewhat complex layering schemes are r the structure is more compact than the side-by-side placement of red, green, and blue

elements currently employed in cathode-ray tubes and LCDs, allowing for higher- reso images.

One problem encountered with stacking numerous transparent organic layers is the fo unwanted optical cavities whose resonances alter the emission spectra of OLEDs. Wh effects are often undesirable and can be eliminated by careful control of layer thicknes composition, some researchers have suggested that multi-color displays can consist o tuned by deliberately created cavities made from dielectric reflecting layers used in pla simple color filters.

The challenge to making full-color polymer-based displays is very different from that fc such displays using small- molecule OLEDs. Solution chemistry makes it difficult to de pattern a polymer pixel of one color, and then repeat the process using a second colo because the solvents employed may dissolve or attack the devices already on the sub

Several schemes have been suggested to dodge this problem. One particularly promi method involves depositing a single blue-emitting polymer, and then selectively diffusi and red dyes into adjacent regions. However, it has proved difficult to keep the diffusir from bleeding into regions nearby. Seiko-Epson Corp. of Nagano, Japan, and Cambri Technology Ltd., Cambridge, England, are pursuing a second approach in which the v polymer constituents of a full-color display are locally deposited using ink-jet printing. I control of the thickness and shape of the droplet, which eventually sets into a high-res pixel, remains an as-yet-unsolved problem.

Even if these solutions become practical, the fact remains that polymer OLEDs made currently available materials have a broad-spectrum color emission. This raises additi barriers to realizing full-color displays. These difficulties have led companies such as I develop early polymer OLED products primarily for highly uniform monochrome displa backlights for LCDs.

Developing reliable organic devices remains a challenge. Charge conduction in these insulating materials requires very high electric fields (1-5 MV/cm) so it is only the extre thinness of OLEDs that enables them to operate at relatively low voltages. That thinne coupled with a reactive top electrode, which is required to ensure efficient injection of into the organic thin film, can contribute to rapid device degradation through the gener subsequent growth of dark spots. The problem becomes especially acute when the de exposed to the atmosphere, which allows oxygen and other contaminants to react with layers. Only a few hours in air is enough to cause significant degradation through dark formation. However, even simple encapsulation in an inert atmosphere can greatly ext useful device operating lifetime to well over 20 000 hours.

Ultimately, organic displays will only be as reliable as their constituent organic materia stable. One recently demonstrated means to extend the lifetime of the devices is throu of organic phosphors. The key to this approach is to reduce the amount of time a light- molecule remains in the excited state. An excited molecule tends to be more reactive t same molecule in its ground state, and the longer it remains excited, the more likely it degrade. Triplet excited states can live for periods approaching 1 second after formati introducing luminescent phosphor dopant molecules, as described earlier, can decrea lifetime to a few hundred nanoseconds, thereby reducing the likelihood they will do da Using phosphor emitters, OLEDs have the potential to achieve operational lifetimes of hundreds of thousands of hours, easily meeting all foreseeable demands on display performance.

The challenges researchers face in developing OLED devices are worth the reward. B they can be printed on flexible surfaces such as polyester, organic light- emitters offer potential for new types of displays and alternative methods of mass-production. Flexib vacuum-deposited, molecular OLEDs have been demonstrated on ITO-coated polyest substrates and other polymers, opening up the possibility of roll-up or conformal displa

curved surfaces [again, Fig. 1]. Vacuum deposition onto plastic sheets also allows ma production of large-area OLEDs via roll-to-roll processing, where organic materials cor the displays are continuously deposited on a flexible substrate translated between two successful development of such a process could result in low-cost manufacture of dis

Organic Transistors

Organic semiconductors are also being applied to thin-film transistors. Developers hop them used for simple but information-packed product labeling and smart cards as well and OLED back panels where large-area, low-cost active matrix transistor arrays are r As in the case of OLEDs, organic thin-film transistors (OTFTs) and circuits have been investigated for many years, but only recently has their performance been sufficient to serious attention from the electronics community.

Organic thin-film transistors [Fig. 5] can contain either a molecular or polymeric chann connecting the source and drain contacts. The gate electrode is first deposited onto ar substrate such as glass or plastic, followed by deposition of the gate insulator, which c of either an organic or inorganic dielectric film. Source and drain electrodes are depos the gate dielectric, and that step is followed by the deposition of the thin-film channel l almost all patterning is done prior to the deposition of the organic material, standard photolithographic techniques can be employed to result in gate lengths of 5 μm or less Alternative methods such as injection molding or direct printing have also been succes employed to generate potentially very low-cost circuits.

The performance of OTFTs is primarily limited by the low electron or hole mobilities of channel materials. Due to molecular vibrations and large intermolecular distances (typ 0.35 nm), conductivity in small-molecule organic films is determined by the rate of elec hole hopping between organic molecules in the channel. Most probably, the mobility o films will not far exceed about 1 $cm^2/V\text{-}s$ at room temperature, which is low, but about that of amorphous silicon already in use in display backplanes. Polymers tend to be le than small molecules, leading to a mobility limit of perhaps two orders of magnitude sn that of small-molecule films.

OTFT circuits such as those recently reported by Philips, Lucent Technologies, and P State University, indicate the rapid advances that are currently being made in this very field. The Philips group has fabricated a 15-bit programmable code generator consistir polymer OTFTs with 2-μm gate lengths. The interconnections between transistors are conducting polymers. Interconnection between the conductors and the transistors was vias formed by an array of pins used to penetrate between layers, intermixing the conc regions of the interconnects and the transistor contacts.

The channel mobility for these particular transistors was only $3 \times 10^{-4} cm^2/V\text{-}s$. This, pl constant of the organic load transistors, resulted in a circuit operating frequency of les Hz. While the performance of this circuit is poor compared to inorganic electronic circu level of integration at such an early stage of development is nevertheless encouraging circuits will one day find applications where cost issues are more important than devic

The Organic Future

The first products using organic displays are already being introduced into the market while it is always difficult to predict when and what future products will be introduced, r manufacturers are now working to introduce cell phones and personal digital assistant OLED displays within the next one or two years. The ultimate goal of using high-efficie phosphorescent, flexible OLED displays in laptop computers and even for home video applications may be no more than a few years into the future.

However, there remains much to be done if organics are to establish a foothold in the market. Achieving higher efficiencies, lower operating voltages, and longer device lifet challenges still to be met. But, given the aggressive worldwide efforts in this area, emi organic thin films have an excellent chance of becoming the technology of choice for t generation of high-resolution, high-efficiency flat-panel displays.

In addition to displays, there are many other opportunities for application of organic thi semiconductors, but to date these have remained largely untapped. Recent results in thin-film transistors provide the best example of an emerging organic electronic techn may soon find commercial outlets in display backplanes and other low-cost electronics

To Probe Further

The first demonstrations of organic light-emitting devices are described in two classic "Organic Electroluminescent Diodes," by C. W. Tang and S. A. Van Slyke, *Applied Ph Letters,* Vol. 51, pp. 913-915 (1987); and "Light Emitting Diodes Based on Conjugated Polymers," by J. H. Burroughes, *et al.,* in *Nature,* Vol. 347, pp. 539-541 (1990).

A recent review of the status of OLED technology can be found in "Prospects and App for Organic Light Emitting Devices," by P.E. Burrows, S.R. Forrest, and M.E. Thompsc *Current Opinion in Solid State and Materials Science,* Vol. 2, pp. 236-243 (1997). Also overview of many of the challenges and opportunities relating to small-molecule organ materials and devices can be found in "Ultrathin Organic Films Grown by Organic Mol Beam Deposition and Related Techniques," by S.R. Forrest, *Chemical Reviews,* Vol. 1793-1896 (1997).

For a complete compendium of the properties of organic materials, refer to *Electronic in Organic Crystals and Polymers,* M. Pope and C. E. Swenberg, second edition (Oxfo

Finally, for those interested in some of the results discussed in the article, see "High E Phosphorescence from Organic Electroluminescent Devices," by M.A. Baldo, *et al., N* 395, pp. 151-154 (1998); "Operating lifetime of phosphorescent organic light emitting P.E. Burrows, S.R. Forrest, T. X. Zhou, and L. Michalski, *Applied Physics Letters,* Vol. 2493-2495 (2000); "Low Cost All-Polymer Integrated Circuits," by C. J. Drury, *et al., A Physics Letters,* Vol. 73, pp. 108-110 (1998); and "A Full-Color Transparent Metal-Fre Organic Light Emitting Device with Simplified Biasing," by G. Parthasarathy, *et al.,* in *Materials,* Vol. 11, pp. 907-910 (1999).

About the Authors

Stephen Forrest (F) has since 1997 served as the chair of the department of electrical engineering at Princeton University in New Jersey. He joined the Princeton Materials and Princeton University in 1992 as the James S. McDonnell Distinguished University of Electrical Engineering , and as director of Princeton's Center for Photonics and Opt Materials. Earlier, he obtained a Ph. D. from the University of Michigan in 1979. From went to Bell Laboratories in Murray Hill, N.J., and then to the University of Southern C where he continued his reseach on semiconductor and organic optoelectronics. He ha on the Lasers and Electro-Optics Society (LEOS) Board of Governors, was an IEEE/L Distinguished Lecturer in 1997, and in 1999 received the Materials Research Society Medal. He is a member of the American Physical Society and MRS, and is a Fellow of Society of America.

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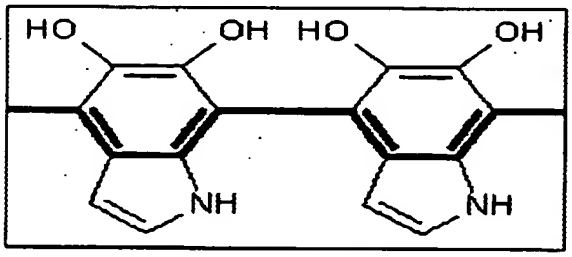
Spectrum editor: Samu

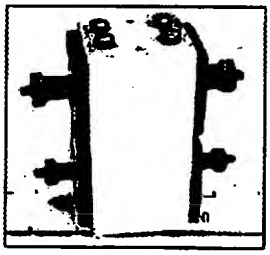
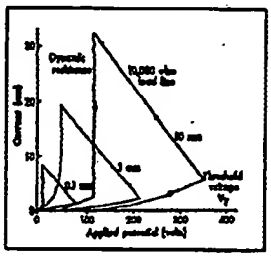
IEEE Spectrum August 2000 Volume 37 Number 8

Advances: Organic Semiconductors

"Here is a more curious case: white cats, if they have blue eyes, are almost always deaf."
Charles Darwin

Organic semiconductors span from quantum mechanics to human disease. For example, like Schroedinger's Cat, Darwin's deaf white kitty illustrates a macro *quantum* phenomenon. This is strong electron-phonon coupling in potent sound-absorbing organic semiconductors such as inner-ear melanin. Likewise, these materials promise exciting new technology such as organic light-emitting diode (OLED) displays, as well as literal "printed" circuits. Finally, the conducting polymer melanin figures in (e.g.) melanoma, deafness, and Parkinson's disease.

a. 

b. 
c. 

a. Melanin, a Typical Polyacetylene (Nicolaus)
b. Melanin Bistable Switch-- *First* Organic Electronic Device ?
c. Voltage-Current Relationship for Melanin Switch, (copyright AAAS, 1974)

> R. Nicolaus: **"The most simple melanin can be considered the acetylene-black from which it is possible to derive all the others..... Substitution does not qualitatively influence the physical properties like conductivity, colour, EPR, which remain unaltered."** from The Nature of Animal Blacks (*"acetylene-black" = polyacetylene)*

I.e., melanin is a synonym for polyacetylene and vice-versa. In retrospect, melanin researchers first

defined much thought "new" in this area, e.g., polyacetylene photoconductivity. Further, many tissues involved in energy transduction and/or electrical activity contain melanin, e.g., the inner ear, brain, and eye. So likely nature first discovered the interesting electrical properties of polyacetylenes.

In this context, the bistable switch above is just the first of three decades of *non-biological* electronic devices which use some "Melanin" as an active element. This device now goes to the Smithsonian institution collection.

That is, Melanin is the first organic semiconductor used in an active electronic device, i.e., one where an electric field modulates current flow. This was a bistable switch, the basic element of computers. Coincidentally, this means melanin is also the first organic material to show "metallic" high-conductivity. It was also the first organic semiconductor used in an energy storage (" battery ") application.

This Prior Art generates an interesting question concerning the 2000 Nobel Prize in Chemistry. This was awarded for a later *chemically-produced* high-conductivity form of another "Melanin". Ironically, this was primarily because this discovery resulted in the eventual (re)discovery of devices like ours, which the prize committee apparently did not know about.

Here are some links.

IEEE review: **The Dawn of Organic Electronics.**

2000 Nobel Prize in chemistry -- " For the (second (?)) discovery and development of conductive polymers ."

Organic Active Devices: Transistors, Switches, etc.

Theory and Modeling of Organic Field-Effect Transistors (pdf)

Bell Labs: "Printing Plastic Transistors" Flexible Plastic Circuits Rubber-Stamped Circuits

IBM Organic Thin film Transistors, Review

More "Printed" circuits

Switching in Melanins A "lost" organic semiconductor device from 1974, --- the same basic active element as later devices, published in *Science*, then reviewed in *Nature*. In retrospect, names count-- the equivalent " Switching in Polyacetylenes " would have been a better title. Some pictures.

This gadget is now in the Smithsonian American Museum of History Collection

A new organic bistable switch. Much progress in 30 years-- This one also emits light.

New Molecular Switch Arrays from Hewlett-Packard

Molecular Scale Organic Switches in "Nanocell" computors

More from James Tour's Lab at Rice. Molecular switches, Nanotechnology, etc..

Sir Nevill Mott on melanins (and thus on "polyacetylenes" in general) " So like and yet so unlike the chalcogenide switches ". Dr. Mott won the 1977 Nobel in physics for his work on disordered materials. Present models for conduction in organic semiconductors derive from his work.

Photovoltaics

Conjugated polymers as photovoltaics

Photoconductivity in melanins.

Organic Light-Emiting-Diodes (OLED's)----

* CDT Kodak IBM Sanyo Siemens Pioneer Dupont Covion *

Miscellaneous

"Opticoelectronic Properties of Disordered Organic Semiconductors" (pdf file). A good review of conduction mechanisms in organic polymers.

Many Organic Semiconductors are Natural Products

The Function of Melanin

Why electronic processes are important in disease

Britanny Spears Guide to Semiconductor Physics (No kidding)

CalPoly Polymer Electronics Lab (many good links)

Intelligent Polymer Research Institute

Big Trouble at Bell Labs: Science Fraud involving Organic Semiconductors

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Nature Vol. 248 April 5 1974, p475 (*News and Views*)

Semiconductors in the human body?

from our Solid State Physics Correspondent

It was realised about 20 years ago that the production of energy from oxygen in the cell mitochondrion was possibly the result of direct electronic transport through haemoproteins rather than the interaction of mobile ions through an aqueous medium (see, for example, Szent-Gyorgyi, *Discuss. Faraday Soc.*, 27, 111; 1959; Carden and Eley, *ibid.*, 115). It was thus necessary to think about a sort of wet solid-state Physics which could embrace reasonably high rates of transport of free electrons or holes through biological solids, especially through certain haemoproteins involved in respiration. Szent-Gyorgyi proposed a theory that a suitable conduction band could be produced by orbital overlaps in amino acid chains and one could predict from this theory that proteins might achieve conductivities in the semiconductor range. The theory was conceptually very attractive but was not widely taken up, largely because it was not at the time susceptible of proof, nor had any investigation ever revealed a way of making analogous but simpler organic materials conduct to the level required.

Now, at least, one biological material has been shown to have a strikingly large conductivity when correctly excited. McGinness, Corry and Proctor, of the University of Texas Cancer Center, Houston, report in ***Science*** **(183, 853; 1974)** that melanins can be made to 'switch' from a poorly conducting to a highly conducting state at fairly low electric fields (say from 101 n cm to 10' n ent at a field of 3 x 101 V cm-1). This remarkable phenomenon occurs both in melanin made synthetically from tyrosine and in that extracted from a human melanoma. The large conduction is not destructive in any way and is reversible;. According to some tests, conduction seems to be electronic rather than ionic. Also tests of a few other likely biological materials in the same form (a compressed solid pellet inside a quartz tube, mildly hydrated and of length ranging from 0. 1 to 10 mm) suggest that the effect is confined to the melanins and the authors note a similarity in the I-Y characteristics of the sample to those of some amorphous inorganic semiconductors which undergo 'threshold switching'. But apart from the major difference in the electric field at which the threshold effect occurs (of the order of 1000 V cm-1 for melanin and 10' V crn-1 for chalcogenide glasses), the current theory of the inorganic switching phenomenon rests on filamentary conduction, leading to a controlled degree of segregation of the constituents of the glass (for example, segregation of pure tellarium from Ge-Te alloys) and possibly strong injection at the electrodes under the high local fields (Bosell and Thomas, Phil. Mag., 27, 665-81; 1973).

Neither of these effects seems even likely in the system described, especially since the switching becomes unstable at thicknesses of chalcogenide greater than a few micrometres. Thus, the suggestion of McGuiness *et al.* that melanin in the human body can be a cause rather than a by-product of disease and that its mode of action can he related to this

'electronic device' action is probably premature, especially considering the preliminary nature of the experiments. A revival of discussion on *in vivo* electronic effects in some biological materials associated with oxidation-reduction is, however, welcome if only because science has perhaps moved far enough since the 1950s that it can now devise adequate tests for the basic theories of transport in wet solids. Also a new approach to the treatment of melanotic diseases may well be stimulated by this particular revival of an intellectually stimulating discussion.

Home

keywords: conductive organic metal polymers polymer metals conductors semiconductors conductors.

Energy Bands

The electronic conductivity of a material is determined by the properties of its constituent atoms or molecules, and by the manner in which they are arranged in the lattice (1). Conductivity can be described in terms of a solid-state model that relates electronic processes to valance and conduction energy bands. The valance band consists of electrons that, because they have relatively low energy, are associated with individual atoms or molecules: the conduction band contains more energetic electrons that are free to move throughout the material in response to applied electromagnetic energy.

The number and mobility of conduction electrons determines the electronic conductivity of a material. If the valance and conduction bands are separated by a small gap, then, at typical temperatures, thermal activity will deplete the valance band and populate the conduction band; such a material is a conductor. If the bands are widely separated in energy, the conduction band will be vacant and the material will be an insulator. A semiconductor is a material whose band structure falls between that of a conductor and an insulator-it can be an insulator at one temperature and a conductor at a higher temperature. Semiconductors can contain impurity atoms whose energy states lie within the gap between the valance and conduction bands; such impurities strongly affect conductivity by donating or accepting electrons.

An important consequence of the existence of energy bands is that they permit electronic processes in one region of a material to affect not only the immediate area, but also the entire structure. Szent-Gyorgyi proposed that common energy levels existed over relatively large dimensions in biological structures, possibly with the cell wall itself as the boundary (2). Evans and Gergely (Szent-Gyorgyi's student) calculated the band gap in hydrogen-bonded models of biopolymers and showed that it would be so large that the biopolymers would behave electrically as insulators (3).

However, if impurity atoms were present, they could donate an electron to the conduction band, or remove one from the valance band, leading to mobile conduction electrons or mobile "holes" in the valance band (4, 5). Szent-Gyorgyi postulated that these electronic processes within the energy bands-electron mobility in the conduction band and charge transfer in the valance band-could give rise to biological phenomena and, indeed, to life itself (6, 7). Figures 4.1 and 4.2. depict his theory as applied to the bioelectrical role of ascorbate.

Fig. 4.1. A. A large protein molecule contains many electron pairs. In this state, a pair of electrons is very stable and unreactive; thus the molecule as a whole is very stable and unreactive. B. A pair of electrons with a negative charge. C. A methylglyoxal molecule with an uncoupled electron pair; i.e. an electron is missing from one of the orbital rings. In this state, the methylglyoxal molecule is a free radical and is highly reactive. It can now accept electrons from another molecule to fill its empty orbital ring. (Reproduced, by permission from Nutrition Today, P. O. Box 1829, Annapolis, Maryland 21404, September/October, 1979.)

For ordinary materials the question of their band structure could be resolved by a coordinated series of X-ray, chemical, and electrondynamics studies. But biological tissue is inhomogeneous and impure, and suitable techniques for carrying out many of the necessary studies on such materials have not yet been developed. Perhaps the most significant problem for the experimentalist is that posed by the universal presence of water in tissue. It is well established that the electrical conductivity of tissue increases sharply with water content (8,9). However, the nature of electrical conduction in tissue under physiological conditions of temperature and moisture-the relative contribution of electronic, protonic, and ionic processes-has not been established despite more than 30 years of study (10). Thus, no clear picture of the band structure in tissue has emerged. Other important solid-state techniques that have been used to study the electronic property of biological tissue include electron paramagnetic resonance (11-13), and photoconductivity (14-16). Again, although the results are consistent with a common-energy-band model proposed by Szent-Gyorgyi, they do not establish it as correct.

Chapter 4 Index

T J C Faes *et al* 1999 *Physiol. Meas.* **20** R1 R10

TOPICAL REVIEW

The electric resistivity of human tissues (100 Hz-10 MHz): a meta-analysis of review studies

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Abstract. The electric resistivity of various human tissues has been reported in many studies, but on comparison large differences appear between these studies. The aim of this study was to investigate systematically the resistivities of human tissues as published in review studies (100 Hz-10 MHz).

A data set of 103 resistivities for 21 different human tissues was compiled from six review studies. For each kind of tissue the mean and its 95% confidence interval were calculated. Moreover, an analysis of variance showed that the calculated means were not statistically different for most tissues, namely skeletal (171 Ω cm) and cardiac (175 Ω cm) muscle, kidney (211 Ω cm), liver (342 Ω cm), lung (157 Ω cm) and spleen (405 Ω cm), with bone (>17 583 Ω cm), fat (3850 Ω cm) and, most likely, the stratum corneum of the skin having higher resistivities.

The insignificance of differences between various tissue means could imply an equality of their resistivities, or, alternatively, could be the result of the large confidence intervals which obscured real existing differences. In either case, however, the large 95% confidence intervals reflect large uncertainties in our knowledge of resistivities of human tissues. Applications based on these resistivities in bioimpedance methods, EEG and EKG, should be developed and evaluated with these uncertainties in mind.

Keywords: electric conductivity, electric resistivity, electric impedance, impedance cardiography, impedance tomography

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"Semiconductor Materials, Junctions, and Devices"

from

"RCA Transistor Manuel"

TECHNICAL SERIES SC–13

Semiconductor devices are small but versatile units that can perform an amazing variety of control functions in electronic equipment. Like other electron devices, they have the ability to control almost instantly the movement of charges of electricity. They are used as rectifiers, detectors, amplifiers, oscillators, electronic switches, mixers, and modulators.

In addition, semiconductor devices have many important advantages over other types of electron devices. They are very small and light in weight (some are less than an inch long and weigh just a fraction of an ounce). They have no filaments or heaters, and therefore require no heating power or warm-up time. They consume very little power. They are solid in construction, extremely rugged, free from microphonics, and can be made impervious to many severe environmental conditions. The circuits required for their operation are usually simple.

SEMICONDUCTOR MATERIALS

Unlike other electron devices, which depend for their functioning on the flow of electric charges through a vacuum or a gas, semiconductor devices make use of the flow of current in a solid. In general, all materials may be classified in three major categories — conductors, semiconductors, and insulators — depending upon their ability to conduct an electric current. As the name indicates, a semiconductor material has poorer conductivity than a conductor, but better conductivity than an insulator.

The materials most often used in semiconductor devices are germanium and silicon. Germanium has higher electrical conductivity (less resistance to current flow) than silicon, and is used in most low– and medium–power diodes and transistors. Silicon is more suitable for high–power devices than germanium. One reason is that it can be used at much higher temperatures. A relatively new material which combines the principal desirable features of both germanium and silicon is gallium arsenide. When further experience with this material has been obtained, it is expected to find much wider use in semiconductor devices.

Resistivity

The ability of a material to conduct current (conductivity) is directly proportional to the number of free (loosely held) electrons in the material. Good conductors, such as silver, copper, and aluminum, have large numbers of free electrons; their resistivities are of the order of a few millionths of an ohm-centimeter. Insulators such as glass, rubber, and mica, which have very few loosely held electrons, have resistivities as high as several million ohm-centimeters.

Semiconductor materials lie in the range between these two extremes, as shown in Fig. 1. Pure germanium has a resistivity of 60 ohm–centimeters. Pure silicon has a considerably higher resistivity, in the order of 60,000 obm-centimeters. As used in semiconductor devices, however, these materials contain carefully controlled amounts of certain impurities which reduce their resistivity to about 2 ohm–centimeters at room temperature (this resistivity decreases rapidly as the temperature rises).

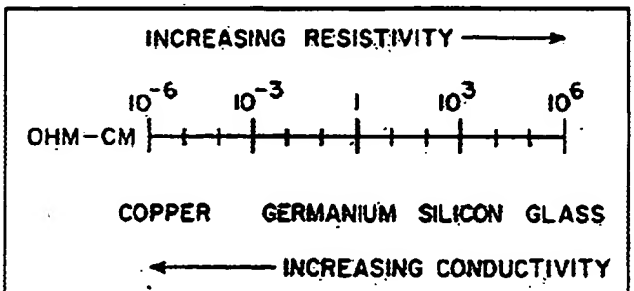


Figure 1. Resistivity of typical conductor, semiconductors, and insulator.

Impurities

Carefully prepared semiconductor materials have a crystal structure. In this type of structure, which is called a lattice, the outer or valence electrons of individual atoms are tightly bound to the electrons of adjacent atoms in electron–pair bonds, as shown in Fig. 2. Because such a structure has no loosely held electrons, semiconductor materials are poor conductors under normal conditions. In order to separate the electron pair bonds and provide free electrons for electrical conduction, it would be necessary to apply high temperatures or strong electric fields.

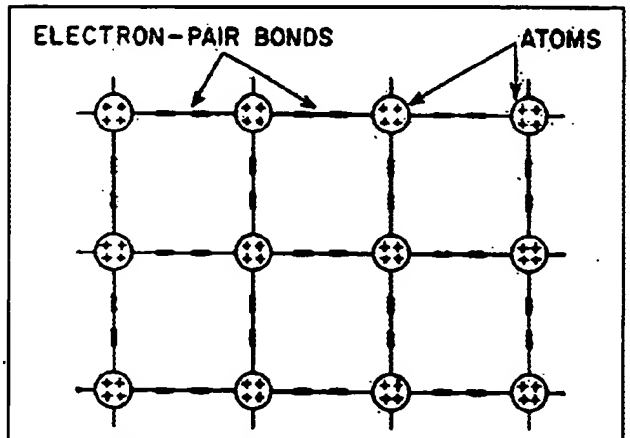


Figure 2. Crystal lattice structure.

Another way to alter the lattice structure and thereby obtain free electrons, however, is to add small amounts of other elements having a different atomic structure. By the addition of almost infinitesimal amounts of such other elements, called "impurities", the basic electrical properties of pure semiconductor materials can be modified and controlled. The ratio of impurity to the semiconductor material is usually extremely small, in the order of one part in ten million. (0.1 ppm)

When the impurity elements are added to the semiconductor material, impurity atoms take the place of semiconductor atoms in the lattice structure. If the impurity atoms added have the same number of valence electrons as the atoms of the original semiconductor material, they fit neatly into the lattice, forming the required number of electron–pair bonds with semiconductor atoms. In this case, the electrical properties of the material are essentially unchanged.

When the impurity atom has one more valence electron than the semiconductor atom, however, this extra electron cannot form an electron pair bond because no adjacent valence electron is available. The excess electron is then held very loosely by the atom, as shown in Fig. 3, and requires only slight excitation to break away. Consequently, the presence of such excess electrons makes the material a better conductor, i.e., its resistance to current flow is reduced.

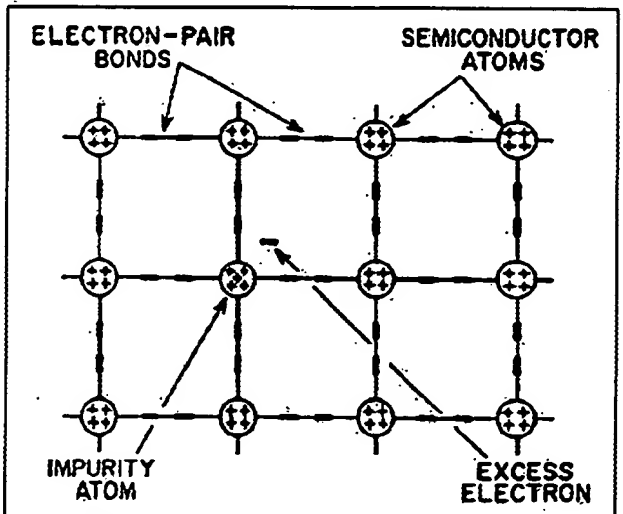


Figure 3. Lattice structure of n-type material.

Impurity elements which are added to germanium and silicon crystals to provide excess electrons include arsenic and antimony. When these elements are introduced, the resulting material is called n–type because the excess free electrons have a negative charge. (It should be noted, however, that the negative charge of the electrons is balanced by an equivalent positive charge in the center of the impurity atoms.

Therefore, the net electrical charge of the semiconductor material is not changed.)

A different effect is produced when an impurity atom having one less valence electron than the semiconductor atom is substituted in the lattice structure. Although all the valence electrons of the impurity atom form electron–pair bonds with electrons of neighboring semiconductor atoms, one of the bonds in the lattice structure cannot be completed because the impurity atom lacks the final valence electron. As a result, a vacancy or "hole" exists in the lattice, as shown in Fig. 4. An electron from an adjacent electron–pair bond may then absorb enough energy to break its bond and move through the lattice to fill the hole. As in the case of excess electrons, the presence of "holes" encourages the flow of electrons in the semiconductor material; consequently, the conductivity is increased and the resistivity is reduced.

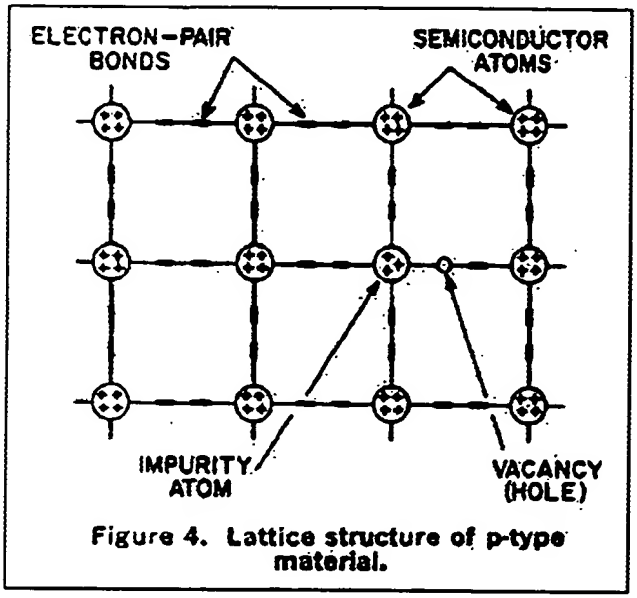


Figure 4. Lattice structure of p-type material.

The vacancy or hole in the crystal structure is considered to have a positive electrical charge because it represents the absence of an electron. (Again, however, the net charge of the crystal is unchanged.) Semiconductor material which contains these "holes" or positive charges is called p–type material. p–type materials are formed by the addition of aluminum, gallium, or indium.

Although the difference in the chemical composition of n–type and p–type materials is slight, the differences in the electrical characteristics of the two types are substantial, and are very important in the operation of semiconductor devices.

P–N JUNCTIONS

When n–type and p–type materials are joined together, as shown in Fig. 5, an unusual but very important phenomenon occurs at the interface where the two materials meet (called "the p-n junction"). An interaction takes place between the two types of

material at the junction as a result of the holes in one material and the excess electrons in the other.

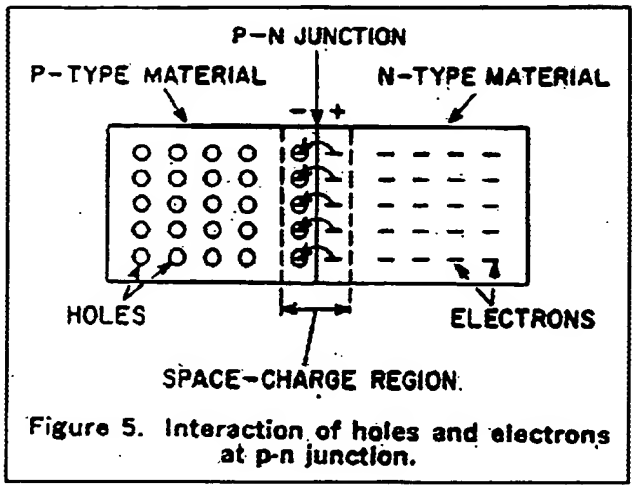


Figure 5. Interaction of holes and electrons at p-n junction.

When a p–n junction is formed, some of the free electrons from the n-type material diffuse across the junction and recombine with holes in the lattice structure of the p–type material; similarly, some of the holes in the p–type material diffuse across the junction and recombine with free electrons in the lattice structure of the n–type material. This interaction or diffusion is brought into equilibrium by a small space–charge region (sometimes called the transition region or depletion layer). The p–type material thus acquires a slight negative charge and the n–type material acquires a slight positive charge.

Thermal energy causes charge carriers (electrons and holes) to diffuse from one side of the p–n junction to the other side; this flow of charge carriers is called diffusion current. As a result of the diffusion process, however, a potential gradient builds up across the space–charge region. This potential gradient can be represented, as shown in Fig. 6, by an imaginary battery connected across the p–n junction. (The battery symbol is used merely to illustrate internal effects; the potential it represents is not directly measurable.)

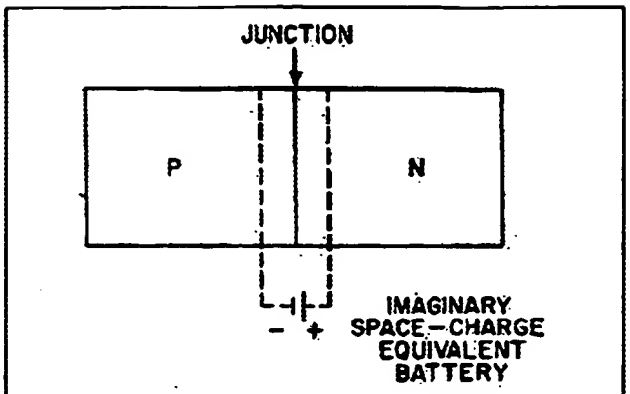
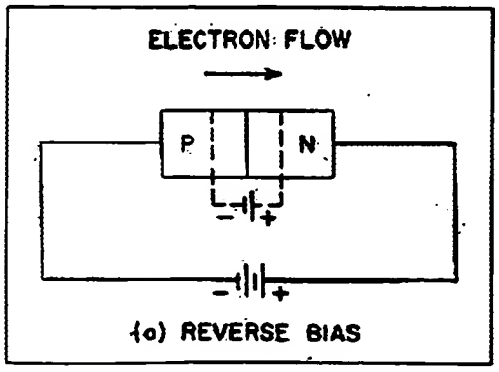


Figure 6. Potential gradient across space-charge region.

The potential gradient causes a flow of charge carriers, referred to as drift current, in the opposite direction to the diffusion current. Under equilibrium conditions, the diffusion current is exactly balanced by the drift current so that the net current across the p–n junction is zero. In other words, when no external current or voltage is applied to the p–n junction, the potential gradient forms an energy barrier that prevents further diffusion of charge carriers across the junction. In effect, electrons from the n–type material that tend to diffuse across the junction are repelled by the slight negative charge induced in the p-type material by the potential gradient, and holes from the p–type material are repelled by the slight positive charge induced in the n–type material. The potential gradient (or energy barrier, as it is sometimes called), therefore, prevents total interaction between the two types of materials, and thus preserves the differences in their characteristics.

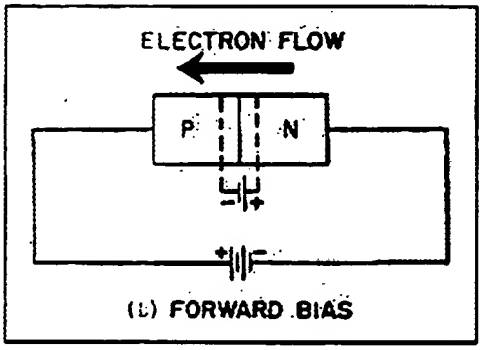
CURRENT FLOW

When an external battery is connected across a p–n junction, the amount of current flow is determined by the polarity of the applied voltage and its effect on the space–charge region. In. Fig. 7a, the positive terminal of the battery is connected to the n–type material and the negative terminal to the p–type material.



In this arrangement, the free electrons in the n–type material are attracted toward the positive terminal of the battery and away from the junction. At the same time, holes from the p–type material are attracted toward, the negative terminal of the battery and away from the junction. As a result, the space–charge region at the junction becomes effectively wider, and the potential gradient increases until it approaches the potential of the external battery. Current flow is then extremely small because no voltage difference (electric field) exists across either the p–type or the n–type region. Under these conditions, the p–n junction is said to be reverse–biased.

In Fig. 7b, the positive terminal of the external battery is connected to the p–type material and the negative terminal to the n–type material.



In this arrangement, electrons in the p–type material near the positive terminal of the battery break their electron–pair bonds and enter the battery, creating new holes. At the same time, electrons from the negative terminal of the battery enter the n–type material and diffuse toward the junction. As a result, the space charge region becomes effectively narrower, and the energy barrier decreases to an insignificant value. Excess electrons from the n–type material can then penetrate the space charge region, flow across the junction, and move by way of the holes in the p–type material toward the positive terminal of the battery. This electron flow continues as long as the external voltage is applied. Under these conditions, the junction is said to be forward–biased.

The generalized voltage–current characteristic for a p–n junction in Fig. 8 shows both the reverse–bias and forward–bias regions.

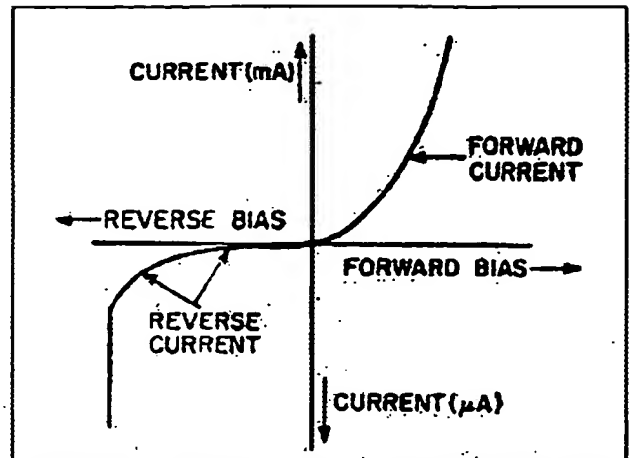


Figure 8. Voltage-current characteristic for a p-n junction.

In the forward–bias region, current rises rapidly as the voltage is increased and is quite high. Current in the reverse–bias region is usually much lower. Excessive voltage (bias) in either direction should be avoided in normal applications because excessive currents and the resulting high temperatures may permanently damage the semiconductor device.

N–P–N and P–N–P STRUCTURES

Fig. 7 shows that a p–n junction biased in the reverse direction is equivalent to a high–resistance element (low current for a given applied voltage), while a junction biased in the forward direction is equivalent to a low–resistance element (high current for a given applied voltage). Because the power developed by a given current is greater in a high–resistance element than in a low–resistance element ($P=I^2R$), power gain can be obtained in a structure containing two such resistance elements if the current flow is not materially reduced. A device containing two p–n junctions biased in opposite directions can operate in this fashion.

Such a two–junction device is shown in Fig. 9.

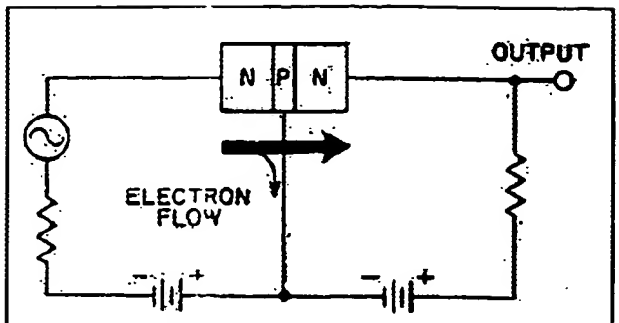


Figure 9. N-P-N structure biased for power gain.

The thick end layers are made of the same type of material (n–type in this case), and are separated by a very thin layer of the opposite type of material (p–type in the device shown). By means of the external batteries, the left–hand (p–n) junction is biased in the forward direction to provide a low–resistance input circuit, and the right–hand (p–n) junction is biased in the reverse direction to provide a high–resistance output circuit. ...

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	First Named Inventor	Gerald A. Mourou
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	Reissue Application No.	09/775,106
	Filing Date	February 1, 2001
	Art Unit	1725
	Examiner Name	Geoffrey S. Evans

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Victor	Elner		
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DECLARATION	ADDITIONAL INVENTOR(S) Supplemental Sheet Page 2 of 2

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Detao	**Du**		
Inventor's Signature		Date	
Name of Third Inventor:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle [if any])	Family Name or Surname		
Subrata K.	**Dutta**		
Inventor's Signature		Date	
Name of Fourth Inventor:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle [if any])	Family Name or Surname		
Victor	**Elner**		
Inventor's Signature		Date	

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U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

DECLARATION	ADDITIONAL INVENTOR(S) Supplemental Sheet

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle if any)	Family Name or Surname
Ron	Kurtz
Inventor's Signature: [illegible signature]	Date: 8-6-04

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle if any)	Family Name or Surname
Paul R.	Lichter
Inventor's Signature	Date

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle if any)	Family Name or Surname
Xinbing	Liu
Inventor's Signature	Date

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle if any)	Family Name or Surname
Peter P.	Pronko
Inventor's Signature	Date

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle if any)	Family Name or Surname
Jeffrey A.	Squier
Inventor's Signature	Date

SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

PTO/SB/51S (05-03)

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U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

SUPPLEMENTAL DECLARATION FOR REISSUE PATENT APPLICATION TO CORRECT "ERRORS" STATEMENT (37 CFR 1.175)

Attorney Docket Number	2115D-000939/DVC
First Named Inventor	Gerald A. Mourou
COMPLETE	
Reissue Application No.	09/775,106
Filing Date	February 1, 2001
Art Unit	1725
Examiner Name	Geoffrey S. Evans

I/We hereby declare that:

Every error in the patent which was corrected in the present reissue application, and which is not covered by the prior oath(s) and/or declaration(s) submitted in this application, arose without any deceptive intention on the part of the applicant.

I/We hereby declare that all statements made herein of my/our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Name of Sole or First Inventor:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle [if any])	Family Name or Surname		
Gerard A	**Mourou**		
Inventor's Signature		Date	
Name of Second Inventor:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle [if any])	Family Name or Surname		
Detao	**Du**		
Inventor's Signature		Date	
Name of Third Inventor:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle [if any])	Family Name or Surname		
Subrata K.	**Dutta**		
Inventor's Signature		Date	
Name of Fourth Inventor:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle [if any])	Family Name or Surname		
Victor	**Elner**		
Inventor's Signature		Date	

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This collection of information is required by 37 CFR 1.175. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 1.8 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

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DECLARATION	ADDITIONAL INVENTOR(S) Supplemental Sheet Page 2 of 2

Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle if any)		Family Name or Surname	
Ron		**Kurtz**	
Inventor's Signature		Date	
Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle if any)		Family Name or Surname	
Paul R.		**Lichter**	
Inventor's Signature	Paul R. Lichter	Date	8-6-04
Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle if any)		Family Name or Surname	
Xinbing		**Liu**	
Inventor's Signature		Date	
Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle if any)		Family Name or Surname	
Peter P.		**Pronko**	
Inventor's Signature		Date	
Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle if any)		Family Name or Surname	
Jeffrey A.		**Squier**	
Inventor's Signature		Date	

PTO/SB/51S (05-03)

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Given Name (first and middle [if any])	Family Name or Surname
Gerard A	**Mourou**
Inventor's Signature	Date

Name of Second Inventor:	☐ A petition has been filed for this unsigned inventor
Given Name (first and middle [if any])	Family Name or Surname
Detao	**Du**
Inventor's Signature	Date

Name of Third Inventor:	☐ A petition has been filed for this unsigned inventor
Given Name (first and middle [if any])	Family Name or Surname
Subrata K.	**Dutta**
Inventor's Signature	Date

Name of Fourth Inventor:	☐ A petition has been filed for this unsigned inventor
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Victor	**Elner**
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Ron		Kurtz	
Inventor's Signature		Date	
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Paul R.		Lichter	
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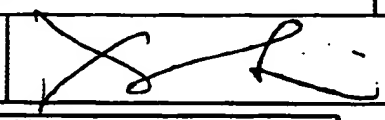
Xinbing		Liu	
Inventor's Signature		Date	Aug. 3, 2004
Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle if any)		Family Name or Surname	
Peter P.		Pronko	
Inventor's Signature		Date	
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Jeffrey A.		Squier	
Inventor's Signature		Date	

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Inventor's Signature	Date

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Detao	**Du**
Inventor's Signature	Date

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Subrata K.	**Dutta**
Inventor's Signature	Date

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Given Name (first and middle if any)		Family Name or Surname	
Peter P.		Pronko	
Inventor's Signature		Date	8/3/04
Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor		
Given Name (first and middle if any)		Family Name or Surname	
Jeffrey A.		Squier	
Inventor's Signature		Date	

PTO/SB/51S (05-03)

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Reissue Application No.	09/775,106
Filing Date	February 1, 2001
Art Unit	1725
Examiner Name	Geoffrey S. Evans

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Gerard A	**Mourou**
Inventor's Signature	Date

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Detao	**Du**
Inventor's Signature	Date

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Given Name (first and middle [if any])	Family Name or Surname
Subrata K.	**Dutta**
Inventor's Signature	Date

Name of Fourth Inventor:	☐ A petition has been filed for this unsigned inventor
Given Name (first and middle [if any])	Family Name or Surname
Victor	**Elner**
Inventor's Signature	Date

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U.S. Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE

DECLARATION	ADDITIONAL INVENTOR(S) Supplemental Sheet Page 2 of 2

Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor
Given Name (first and middle if any)	Family Name or Surname
Ron	Kurtz
Inventor's Signature	Date
Name of Additional Joint Inventor, if any:	☐ A petition has been filed for this unsigned inventor
Given Name (first and middle if any)	Family Name or Surname
Paul R.	Lichter
Inventor's Signature	Date
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Inventor's Signature	Date
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Given Name (first and middle if any)	Family Name or Surname
Jeffrey A.	Squier
Inventor's Signature	Date 8/12/04